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Analysis of Various Connection Configuration of Photovoltaic Module under Different Shading Conditions

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Abstract

The solar photovoltaic (PV) systems are facing serious problems due to unavoidable losses in their system because of partial shading which is a commonly encountered issue in a PV (photovoltaic) system. This paper analyses the various losses due to partial shading on different photovoltaic module connection configurations under non-uniform illumination and partial shading condition. Each solar module is composed of 36 solar cells which are interconnected in various connection configurations like Simple Series configuration (SS), Series-Parallel configuration (SP), Total-Cross Tied configuration (TCT), Bridge-Linked configuration (BL), and Honey Comb configuration (HC) using MATLAB software. Bypass diodes are also connected to avoid hotspot conditions in a photovoltaic module. This analysis helps to study characteristics of the module with a specific configuration in response to different types and levels of partial shading. The module configurations have been compared on the basis of various partial shading losses. Results shows that under non uniform irradiance condition as well as different shading conditions SP and HC module interconnection configuration in a PV modules is more prone to power losses as compared to other module interconnection configuration.

Keywords: Energy sources, renewable energy system, partial shading, simulation, solar photovoltaic cell interconnection scheme.

INTRODUCTION

Due to the ever increasing energy demand, PV (Photovoltaic) power is becoming an important source of electrical energy as among all the renewable sources, PV power is easily accessible & environmental friendly. PV power is gaining more importance in distributed generation systems as well as standalone system. PV cell convert solar energy to electricity when exposed to sunlight. In order to get required amount of current (Ampere) and voltage (volts) many PV cells are interconnected into a single unit called a PV module. Generally a PV module is composed of 36 cells which are connected in series, but other connection configurations are also possible. All the PV cells in a module are supposed to have identical electrical properties, but these properties changes when they are exposed to different levels of solar irradiance leading to mismatch losses. This mismatch causes a serious & unavoidable trouble called partial shading. The shaded cells becomes reverse biased and act like a load to absorb the power, leading to hot spot problem that may cause irreversible damage to the module. Partial shading can be caused by snow, tree shadow or bird dung covering PV module surface. In a large PV system occupying a wide area of land, moving clouds is also the cause of partial shade. In building integrated PV systems, PV modules installed with different orientations to fit the building outer wall receive different levels of irradiance, which is a situation similar to partial shading. There are various factors that contribute to the reduction of output power from PV arrays. One of the major factors is partial shading [1]. Practically all the PV cells in a module do not operate under uniform irradiance so the string (series connected cells) current limits to current of the lowermost short circuit (SC) current [2]. The major cause for the unequal SC current is the partial shading (PS) due to clouds, nearby trees, buildings etc. Partial shade causes hot spots in the shaded cells which can damage the cells [3]. To prevent PV cells from damage due to hotspots, bypass diodes are connected with the PV cells [4]. When the shaded cells in the PV module become reverse biased, the bypass diode connected in antiparallel begins to bypass the current exceeding the SC current of the shaded cells. Bypass diodes conduct during non- uniform condition, the power- voltage (PV) curves shows multiple maxima. Shaded module in series with other unshaded modules limits the string current thereby reducing the maximum power generated by the array [5], [6]. The reduction in power depends on the module interconnection scheme and shading pattern. Different interconnection schemes such as series–parallel (SP), total cross tied (TCT), and bridge linked (BL) are introduced in the literature [7], [8] to interconnect the cells in the module. Study of mismatch losses in the array by changing the interconnection scheme of the modules in PV arrays have been addressed [9]–[11]. Investigation on fault tolerance [12] in different interconnection schemes shows that TCT or BL are comparatively less susceptible to electrical mismatches. The study of reliability, which is an important parameter for assessing the operational life time of a PV array, indicates that the life of an array is almost doubled when crossties are introduced in the array [13]. Employing modularized network based on crossties increases the operating life of PV arrays by 30% [13]. The electrical performance of a PV module with SP, TCT, BL, SS (simple series), and HC (honey comb) interconnection configuration is analysed using piecewise linear parallel branches model [14]. The five interconnection schemes are compared for their maximum power and fill factor and it is found that the TCT configuration shows a superior performance over the other four configurations also an optimal topology was suggested considering the effect of change in interconnections among the modules within a shaded PV array on its maximum power point (MPP) using optimisation technique. In this analysis SP array is chosen for experimentation [15]. In this paper, the performance of a PV module with SS (simple series) and HC (honey comb),SP, TCT and BL connection configurations is analysed under different shading conditions by using a MATLAB /Simulink model. In this study a 5x5 TCT array is modelled, the connection of array is kept fixed as TCT connection and its internal module connections are changed in different connection configuration to observe the effect on output power. The system performance is investigated for different shading condition.

PV CELL MODELLING

In PV cell modelling single diode model is the most preferably used model. In this paper the single diode model of the PV cell is implemented. The PV cell current is given by (1).

$$I = [I_{ph}\text{-}I_o(e^{\frac{q(V+RsI)}{AKT}} - 1) - \frac{(V+RsI)}{Rsh}] \quad (1)$$

where *V* and *I* represent the PV cell output voltage and current respectively, *Iph* is the light generated cell current (photo current), *Rs* and *Rsh* are the solar cell series and shunt resistances, I0, the reverse saturation current, *A* is a dimensionless junction material factor, *K* is Boltzmann‟s constant (1.38 × 10-23 J/K), *T* is the temperature in Kelvin and *q* is the electron charge (1.6 × 10-23 C) respectively.

At the Standard test conditions: Irradiance 1000W/m2, cell junction temperature 250 C, and reference air mass 1.5 solar spectral irradiance distribution definite number of such solar cells is connected in series to constitute a PV module. The nonlinear output characteristic of the PV module results in a unique MPP on its PV characteristics.

ARRAY INTERCONNECTION SCHEMES

In a PV array, the interconnection scheme refers to the manner in which modules are interconnected in the array. The widely used interconnection schemes reported in the literature [16] are the SP, TCT, HC and BL configuration. Comparison of different interconnection schemes based on shading conditions and shading levels reveals that the TCT scheme is considered to be the better scheme for reducing the losses under most of the shading conditions .Also in the literature it is found that crossties increases the operating life of PV arrays by 30% [13]. So in this analysis, an array used is of fixed TCT connection (5x5) throughout the analysis and only module connection configurations are changed to study the effect of changing module connection configuration for partial shading conditions

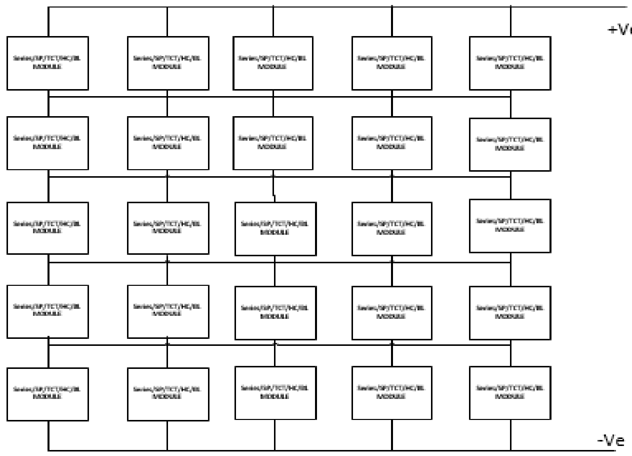

Figure 1: 5x5 TCT array.

MODULE TOPOLOGIES

Many PV cells are interconnected into a single unit to make a PV module. Normally a PV module is composed of 36 cells connected in series, but other connection configurations are also possible. The widely used interconnection schemes are the SP, TCT, HC and BL configuration The SP scheme consists of a series of modules in a string and a number of such strings are connected in parallel. The TCT configuration is obtained by connecting ties across each junction. The BL interconnection scheme is derived from the connections in a bridge rectifier. Fig. 2 shows interconnection schemes in a 6× 6 PV module.

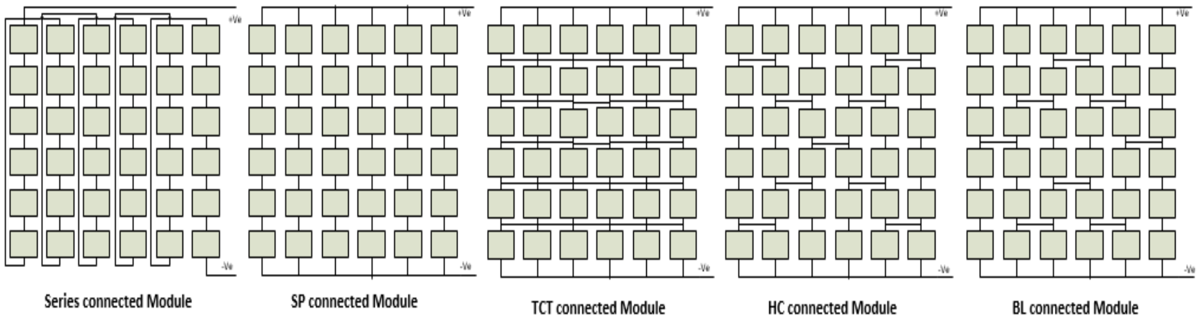

Figure 2: Module Connection Topologies.

PARTIAL SHADING CONDITIONS.

Partial shading is a frequent phenomenon that occurs when some cells within a module or array are shaded by buildings, birds, passing clouds, or some other object. Since the short-circuit current of a PV cell is proportional to the insolation level, the partial shading effect is a reduction of the photocurrent for the shaded PV cells while the unshaded cells continue to operate at a higher photocurrent. Since the string current must be equal through all the series-connected cells, the result is that the shaded cells operate in the reverse bias region to conduct the larger current of the unshaded cells [17]–[23]. The shaded cells consume power due to the reverse voltage polarity. Therefore, the maximum extractable power from the shaded PV array decreases. The high bias voltage may also lead to an avalanche break down. This, in turn, may cause the thermal break down of the cell, creating a so-called hot spot. If untreated, excessive heating can result in cell burn out and create an open circuit in the shaded string. This hot spot can be avoided by using the bypass diodes. These diodes are connected parallel to the cells to limit the reverse voltage and, hence, the power loss in the shaded cells. The reduction in power depends on the module interconnection scheme and shading pattern. Different interconnection schemes such as series–parallel (SP), total cross tied (TCT), and bridge linked (BL) are used to interconnect the modules in the array. Similarly PV module interconnection configuration

with SP, TCT, BL, SS (simple series), and HC (honey comb) also plays vital role in non-uniform partial shading condition.

(A) Types of Shade

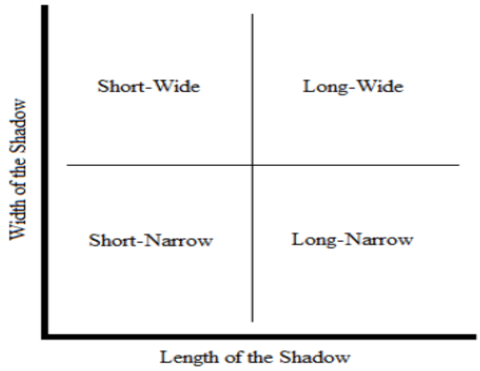

Figure 3: Types of Shades

Most widely considered shades for analysis purpose are short-wide (SW), short-narrow (SN), long-wide (LW), and long-narrow (LN) PS conditions, as shown in Figures, here two special cases such as diagonal shade (DI)& random shade is also included in analysis. A 5 x 5 PV array is used to demonstrate each simulated PS condition, with white indicating the cell is under full available irradiation and black indicating the cell is shaded.

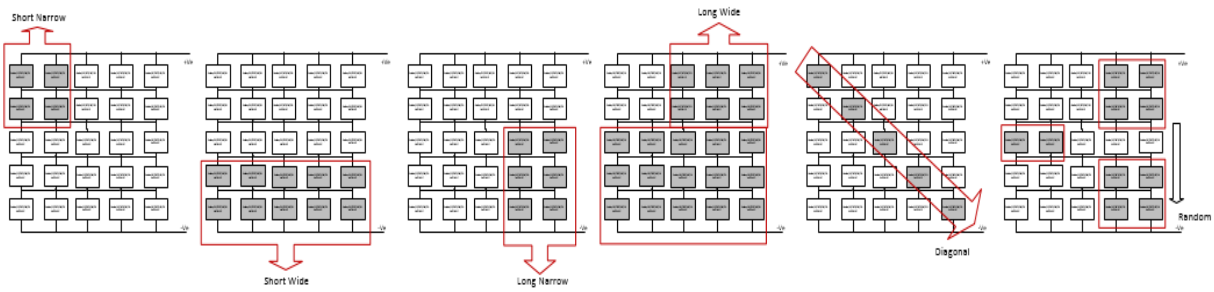

Figure 4: Diagram of Different shaded Modules.

VI. RESULTS AND DISCUSSION.

The simulations are carried out using MATLAB/Simulink environment. All four configurations namely SS, SP, TCT, BL, and HC configuration are compared for their losses under partial shading conditions. The comparison is made based on the shading level and type of shading and the results are presented. Fig.5. shows the plots between mismatch losses against shaded panel insolation under different shading patterns for different interconnections. The shading conditions are shown in fig.4

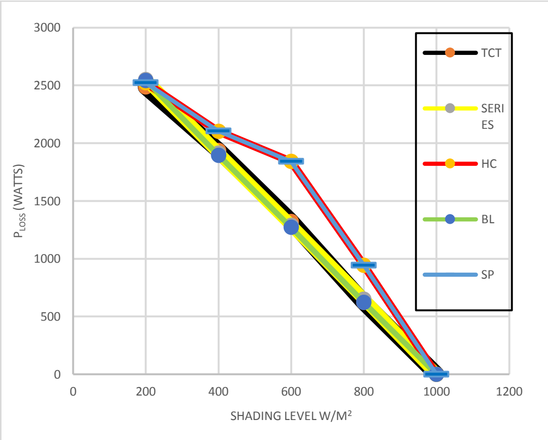

Fig. 5. shows the plots between losses against shaded panel insolation under different shading levels for different interconnections

A 5x5 TCT connected array is modelled. As per literature TCT connection found more superior over others this connection is selected for an array. The module interconnection configuration are changed from SS, SP, TCT, HC, and BL. The respective models are simulated under different shading levels and results are presented as shown in fig.5. SP and HC are the two connections found most affected by changing shading levels. Different shading levels are nothing but non uniform insolation condition which is quite frequent in PV plants.

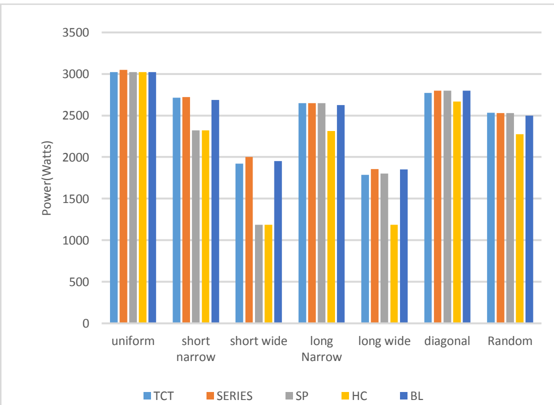

Figure 6(a): shows the plots between Power outputs under different shading patterns for different interconnections.

Fig 6(a) indicates the power output of a 5X5 TCT array with changing module connection configuration as TCT, SERIES, SP, HC and BL. Under uniform irradiance condition array produces approximately same output for all possible module connection configuration. Under all shading condition SP and HC connection produces less as compared to other configurations.

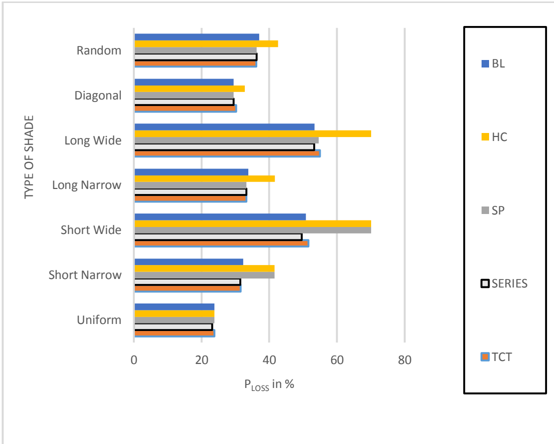

Figure 6(b): shows the plots between P_{loss}% under different shading patterns for different interconnections

Fig 6(b) indicates the plot between shading patterns and P_{Loss} in %. P_{Loss} is calculated by

$$PLoss\% = \frac{P(practical) - P(actual)}{P(practacal)} * 100 \quad (2)$$

$P_{(practical)}$ is the total power of array without losses it is 3969Watts.

$P_{(actual)}$ is the power after considering various losses.

1) Uniform Irradiance condition: Fig 6(b) shows the % losses in power at uniform irradiance condition. This power is less than P (practical) because of mismatch losses in the array.
2) Short and long Narrow Shading Conditions*:* Fig. 6(a) and (b) show the simulation plots (a) between Power output and shading level (b) shading losses and insolation under short and narrow shading conditions. The insolation of the unshaded module is kept at 1000 W/m², while the insolation level of the shaded module is varied from kept at 600 W/m². In each case, the losses

caused by shading are calculated and plotted in Fig.6 (a) and (b). It is observed that in short and long narrow condition a TCT array with module interconnection as SP and HC configuration shows the maximum losses (41.54%)

3) Short and long Wide Shading Conditions*:* It is observed that in all Series, SP, TCT, HC and BL configurations, there is a significant increase in the losses with increase in shading level .In Short and Long wide condition SP and HC shows maximum losses (70.15%).
4) Diagonal Condition: It is observed that in diagonal condition the power losses decreases comparatively. In diagonal condition HC and TCT configuration shows the maximum losses (11.75%)
5) Random Conditions*:* In Random condition HC configuration shows the maximum losses (32.79%)
6) In all the aforementioned cases, it is observed that the SP and HC module interconnection configuration experiences maximum power losses under different shading conditions.

CONCLUSION

In this paper, a simulation method is used for analysing PV modules with five different cell connection configurations: SS, SP, TCT, BL and HC. The evaluation of the five connection configurations has been carried out by using a 36 cells in a module and comparing the maximum powers and the P_{loss} for the five connection schemes. The effects of partial shading on SP, BL, HC and TCT module interconnection configurations have been investigated under changing illumination conditions. The effects of partial shading was studied for different shading patterns. Results show that under both i.e. changing irradiance condition and different shading condition SP and HC module interconnection configuration in a PV modules is found more prone power losses.

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